Earthquakes

Chapter 3

Learning Objectives

- Understand how scientists measure and compare earthquakes
- The processes behind earthquakes, i.e. faulting, tectonic creep, and the formation of seismic waves
- Which global regions are most at risk for earthquakes and why
- Understands the effects of earthquakes, such as shaking
- Learn the other hazards linked with earthquakes
- Understand the important natural service of earthquakes
- Understand how human beings interact with and affect the earthquake hazard
- Understand how we can minimize seismic risk and what can be done to protect ourselves

Earthquake From Disasters to Catastrophes

- Earthquakes are devastating events
  - These earthquakes can be **catastrophic** when the population is huge or when structures are not built to withstand an earthquake
- Earthquakes may **develop from the movement of magma or sudden ground subsidence**.
- **Fault movement allows an abrupt release of energy, usually after a long, slow accumulation of strain**
- **Fault rupture can take place at the surface and displacement can take place at considerable depth**

Earthquake Damage

(a)

(b)

(c)

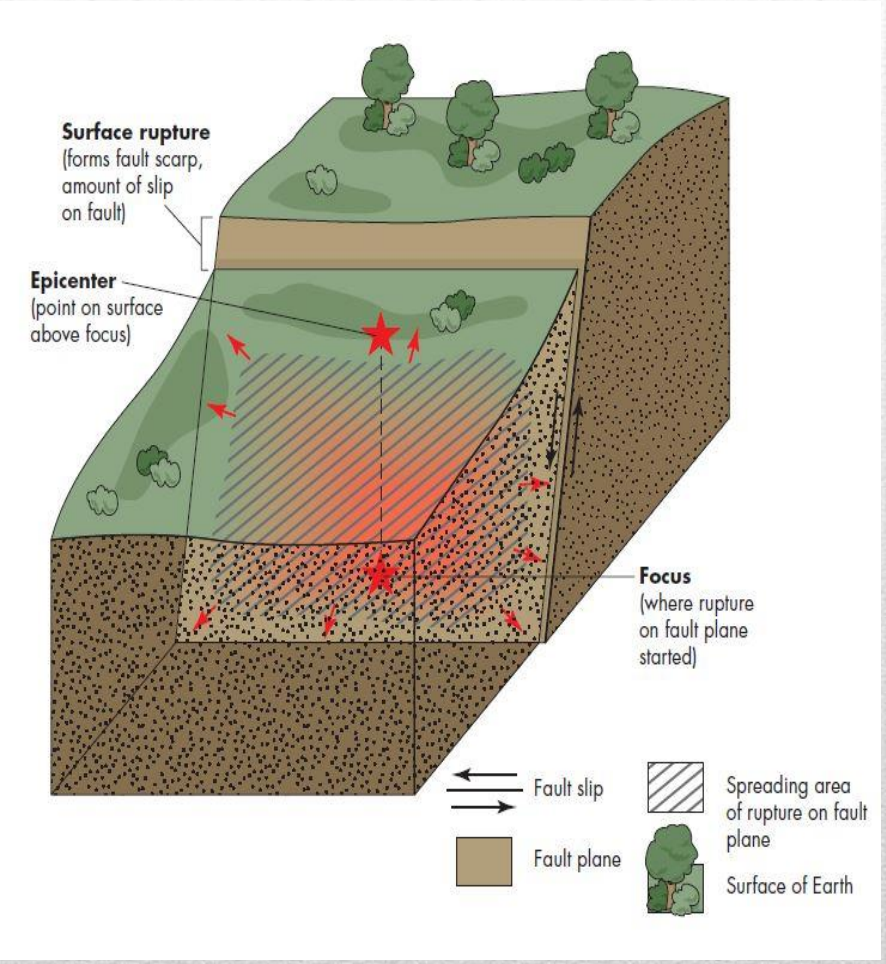
(d)

Earthquakes

- A **vibration in the Earth produced by shock waves resulting from a sudden displacement along a fault**.
- Earthquakes may also **develop from the movement of magma or sudden ground subsidence**.
- **Fault movement allows an abrupt release of energy, usually after a long, slow accumulation of strain**
- **Fault rupture can take place at the surface and displacement can take place at considerable depth**

Introduction to Earthquakes

- **<u>Earthquakes are compared by the amount of energy released</u>**
- **<u>Magnitude</u>** – the relative amount of energy released during an earthquake
- **<u>Shaking Intensity</u>**– intensity scale devised by Giuseppe Mercalli in 1902
  - Updated to the **<u>Modified Mercalli intensity</u> scale**
- **<u>The area where the earthquake starts is called the Epicenter</u>**
  - This is where the ruptured rocks broke to produce the earthquake



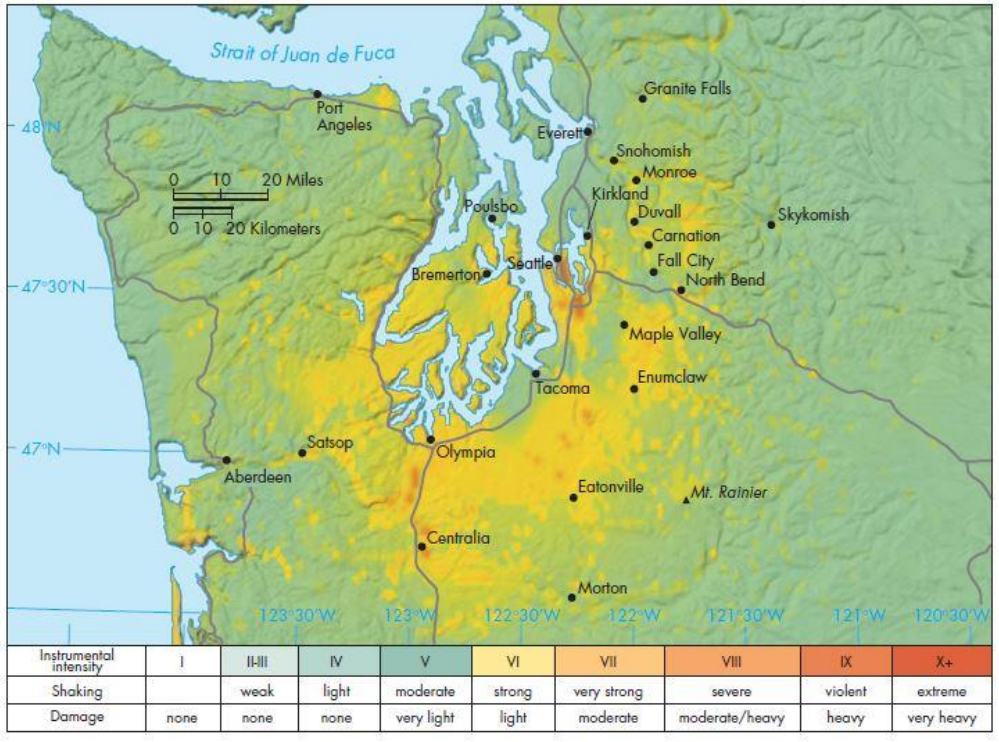
Earthquake Magnitude and Intensity

- **Magnitude** - is **determined from an estimate of the area which ruptured along a fault plane during the quake**
- It is calculated on a logarithmic scale
- Each difference in scale is 32 times more intense than the previous
  - 32 times more energy is released
  - Magnitude scale was developed by Charles Richter
- Recently "**Moment Magnitude** " has been developed to be used by seismologists
- Used to describe very large earthquakes or – **the Earthquake Intensity**
- **Moment Magnitude** estimates the area of rupture along the fault plane during a quake, the amount of movement or slippage along the fault, and the rigidity of the rocks near the focus of the quake
- **Used to prepare online *Community Internet Intensity Maps***
- To help identify where the greatest shaking could take place, ***shake maps*** are developed to help identify where the greatest shaking could take place

Instrumental intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	not felt	weak	light	moderate	strong	very strong	severe	violent	extreme
Damage	none	none	none	very light	light	moderate	moderate/heavy	heavy	very heavy

Instrumental Intensity map for the 1994 Northridge, California earthquake -- M6.7

The 2001 Nisqually, Washington, earthquake -- **M**6.8



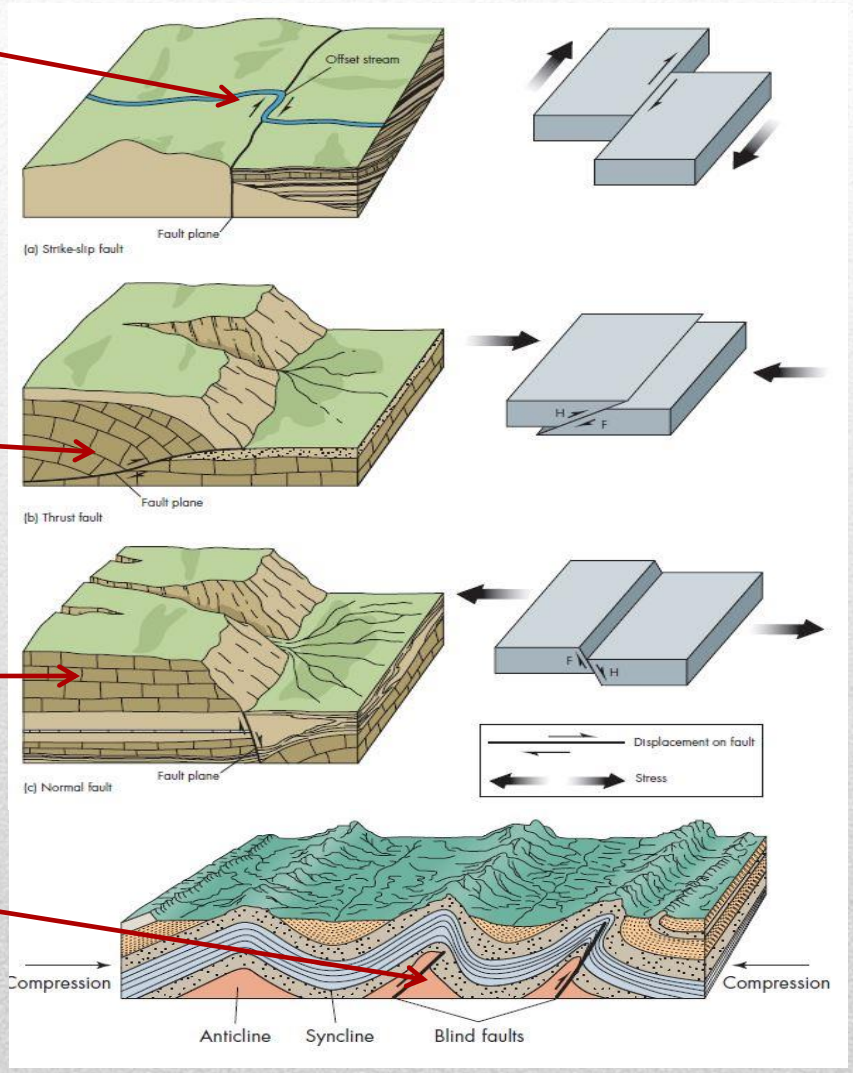
Instrumental intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking		weak	light	moderate	strong	very strong	severe	violent	extreme
Damage	none	none	none	very light	light	moderate	moderate/heavy	heavy	very heavy

Earthquake Processes

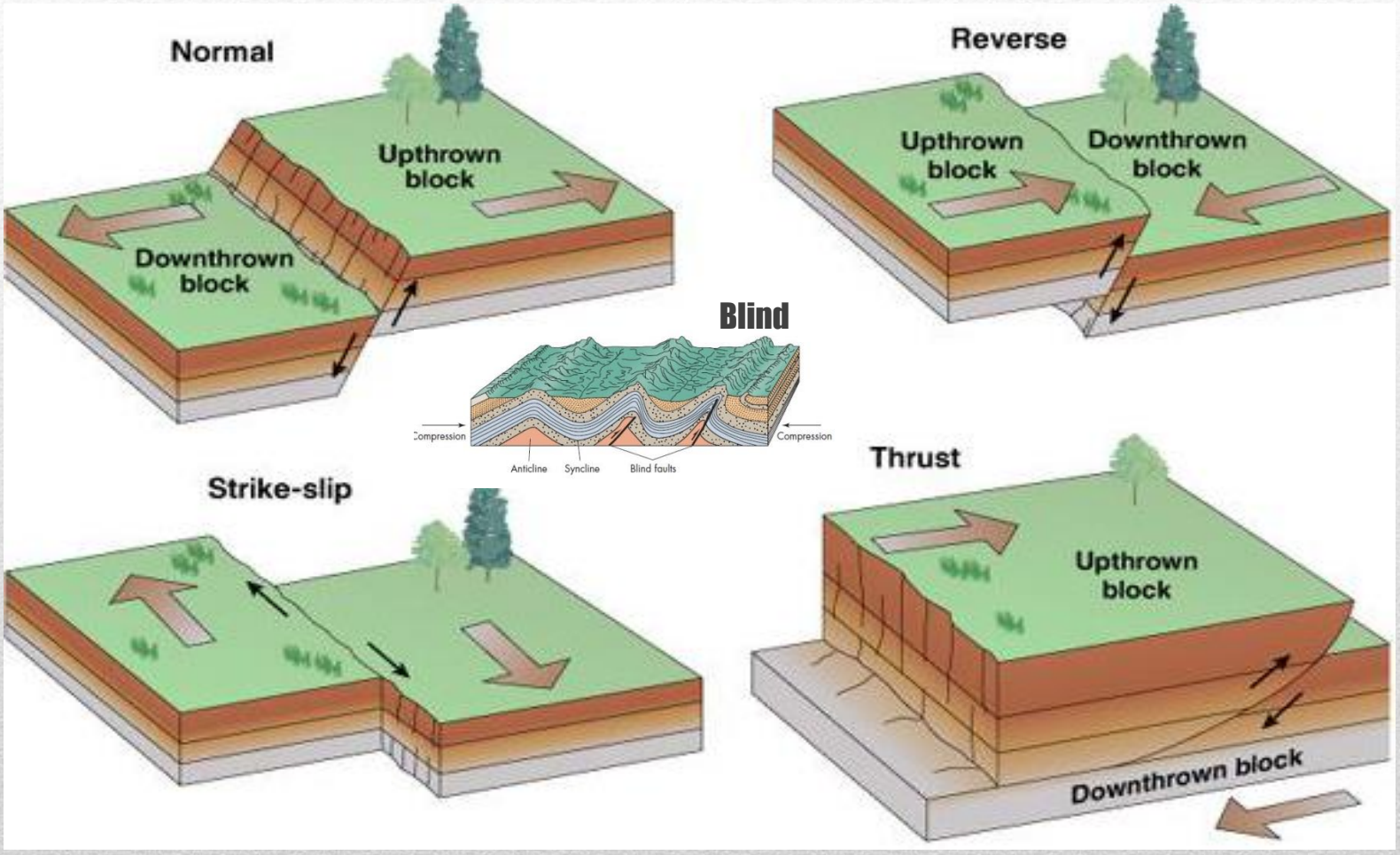
- **Process of Faulting**
  - A **fracture or fracture system** where rocks have been **displaced**
  - Long-term rate of movement is known as the ***slip rate***
  - When the **rupture begins**, it starts at the **focus** and then **propagates up, down, and laterally along the fault plane** during the earthquake
  - The sudden rupture of the rocks produces ***seismic waves***
  - Basically the earthquake **releases pent-up energy** of the strained rocks as **waves of energy**

Types of Faults

- **Types of faults**
  - **Strike Slip – Transform** -a block of crust moves mainly in a horizontal direction
  - **Dip-Slip** – A block of the crust moves mainly in a vertical direction
    - **Over-thrust Fault** – Hanging wall moves over the foot wall at an angle
    - **Normal or Reverse Fault** – Hanging wall moves up or down relative to the foot wall
  - **Blind Fault --** Fault does not extend to the surface of the earth



Types of Faults



Faults

- **Fault Activity**
  - **Active-** if movement during the last 200 – 10,000 years
  - **Potentially Active-** if movement during the 10,000 – 1,650,000 Years
  - **Inactive** – if movement during 65,000,000 to 4.6 billion years ago – the age of the earth

- **Faulting results when rock is broken under stress and displacement happens**
  - **Fault zones --** an area of weakness in the crust
  - **Fault line** – the intersection a fault zone with the Earth's surface
  - **Fault scarps** – steep cliffs that represent the edge of a vertically displaced block

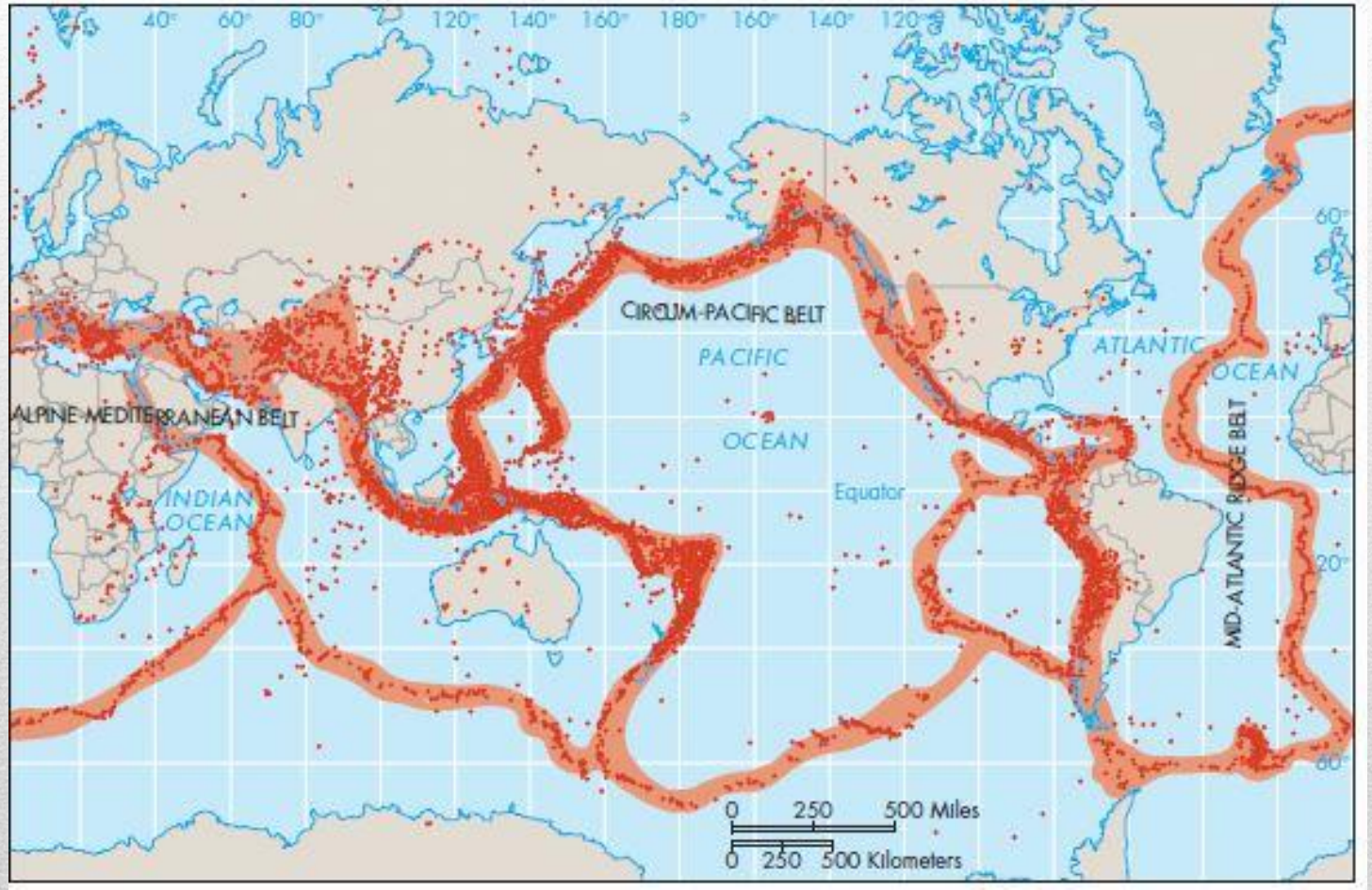
Tectonic Creep and Slow Earthquakes

- **Tectonic Creep** – the gradual movement along a fault which can't be felt

  - These are called **slow earthquakes or fault creep**
  - Slowly causes damage to anything built over the land
    - Example: Suncrest housing development built on old slide or creep
    - Roads are cracking and sliding down the mountain

- **Newly recognized using GPS devices used to capture geodetic movement**

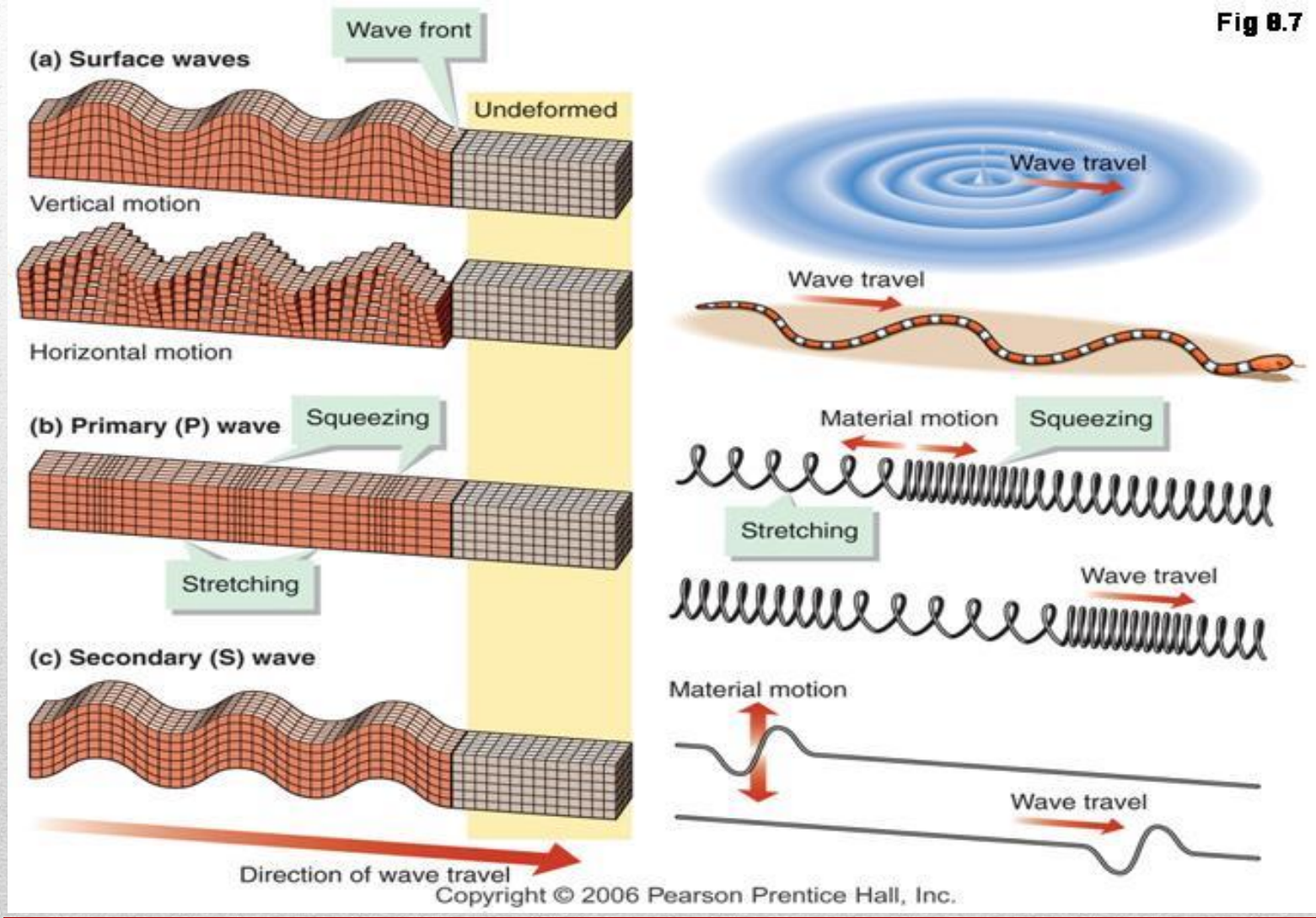
Earthquake Distribution in Regards to Plates



Seismic Waves

- **Start at the Focus – or the epicenter of the earthquake.** (Waves move out from the epicenter like waves in water when rock thrown in)
  - **P Waves** – **Compressional waves** which move through the Earth like sound waves alternately compressing and relaxing the medium that they pass through (**like a slinky**). Moves through **both solids and liquids and gases**
  - **P Waves** move **more quickly through solids** than through liquids
  - When **P Waves** reach the surface of the earth they can be heard by animals and birds
    - This is not the sounds that people hear just before an earthquake, which is sound of objects shaking

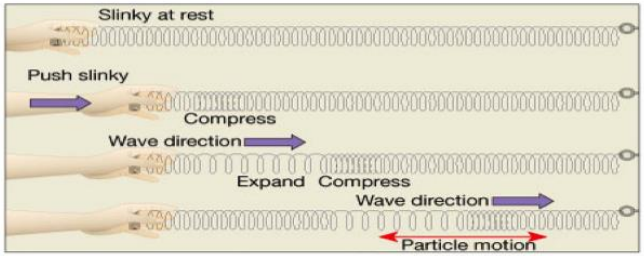
Seismic Waves



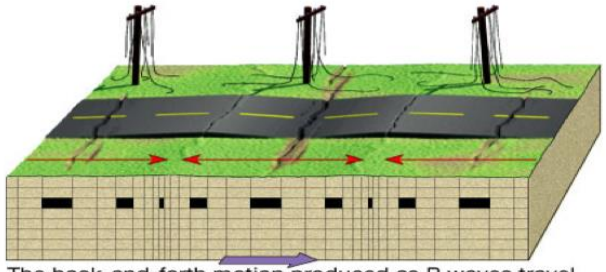
Seismic Waves

- **S Waves**– **Shear or secondary waves which move strong side-to-side, up and down slowing moving waves**
  - The **up and down movement (sideways shear)** produced a whipping back and forth moment
  - **This sideway shearing motion which does not allow for the wave to spring back in liquids**
  - **S Waves** can **only move through solids**
  - **Both P waves and S waves** are "**body waves**" because they **develop in the body of the earth**
- **Surface waves** immediately after the P and S waves arrive on the surface and producing a **strong side-to-side movement as well as the up-and-down "rolling" motion**
  - One type of **surface wave** is called a ***Love Wave*** which especially damages foundations

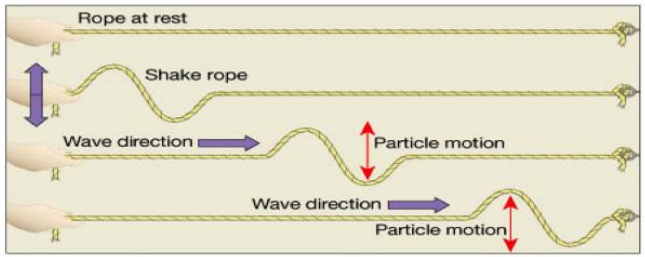
52cd_SeismicWave_SP.swf



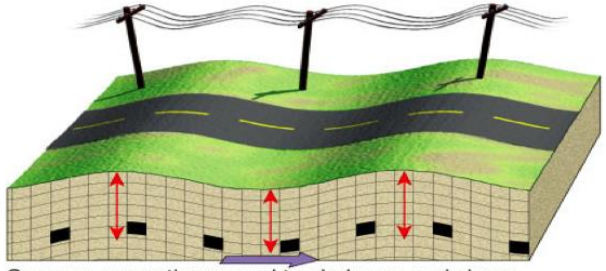
P waves are compression waves that alternately compress and expand the material through which they pass.



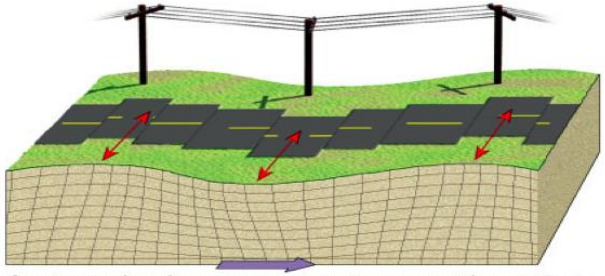
The back-and-forth motion produced as P waves travel along the surface can cause the ground to buckle and fracture.



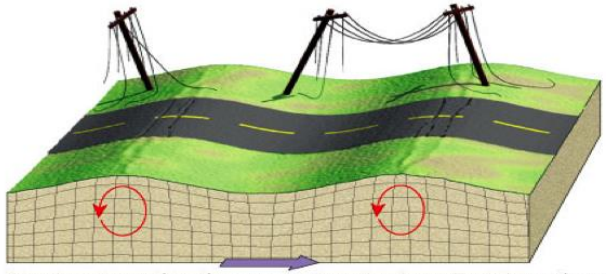
S waves are transverse waves which cause material to shake at right angles to the direction of wave motion. The length of the red arrow is the displacement, or amplitude, of the S wave.



S waves cause the ground to shake up-and-down and sideways.



One type of surface wave moves the ground from side to side and can damage the foundations of buildings.



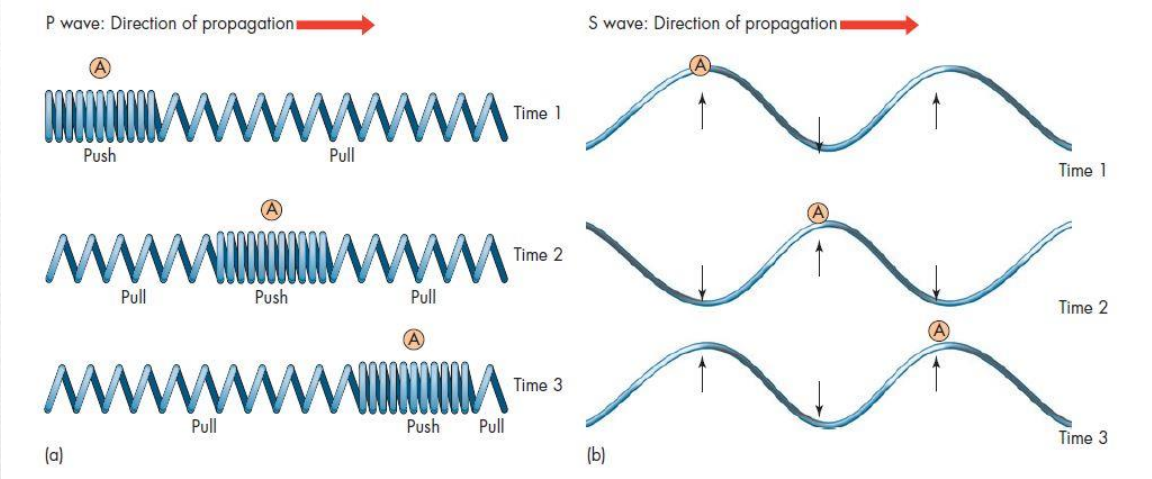
Another type of surface wave travels along Earth's surface much like rolling ocean waves. The arrows show the movement of rock as the wave passes. The motion follows the shape of an ellipse.

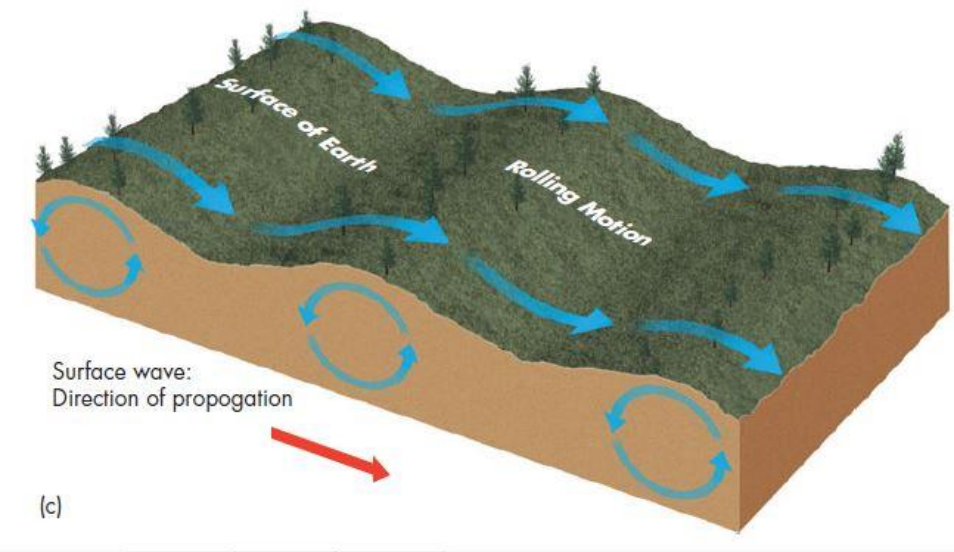
Earthquake Shaking

- **Three important factors** determine the shaking you will experience during an earthquake
  1. **Earthquake magnitude**
  2. **Your location in relation to the epicenter and direction of rupture**
  3. **Local Soil and rock conditions**

- **Generally strong shaking may be expected from earthquakes of moderate magnitude (M 5 – 5.9) or larger**
- **These types of earthquakes will cause the ground to rock and roll damaging building and other structures**
- **DUH!!!!!**

Seismic Waves

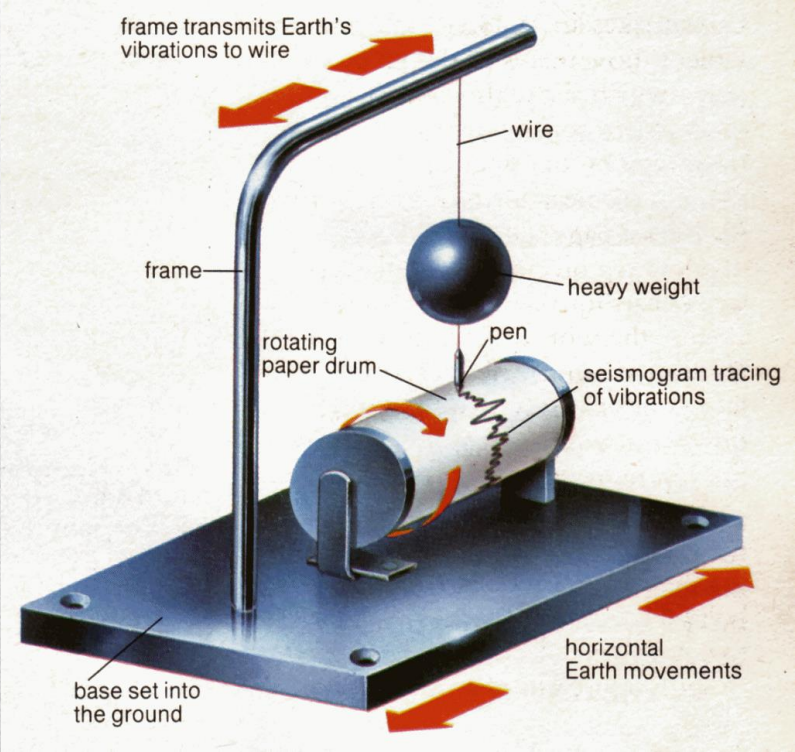




Earthquake Shaking

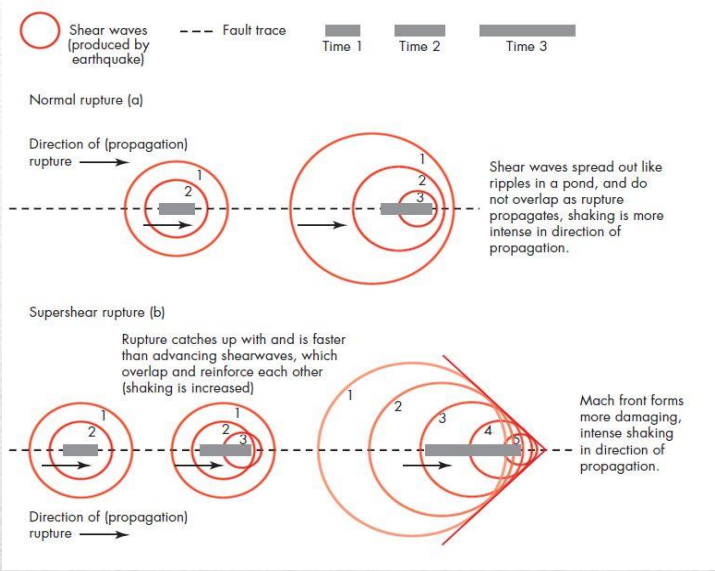
- **Distance from the Epicenter**
  - Using **Seismographs** which produce a seismogram, the epicenter can be located by looking at the travel speed of the P and S waves
  - Scientists use triangulation from more than 4 seismic centers to locate the Epicenter
- **Depth of Focus**
  - The **depth of the earthquake focus** determines how much "**shaking**" will happen
  - The deeper the focus the less shaking is felt on the surface
  - Seismic waves lose much of their energy (***attenuation***) if the focus is deep in the earth
- **Direction of Rupture**
  - Although the rupture from the focus may move in many directions **the path of the greatest rupture can focus the earthquake energy**. This is the **directivity**.
    - **Contributes to the *amplification of seismic waves and shaking***

Seismograph



Earthquake Shaking

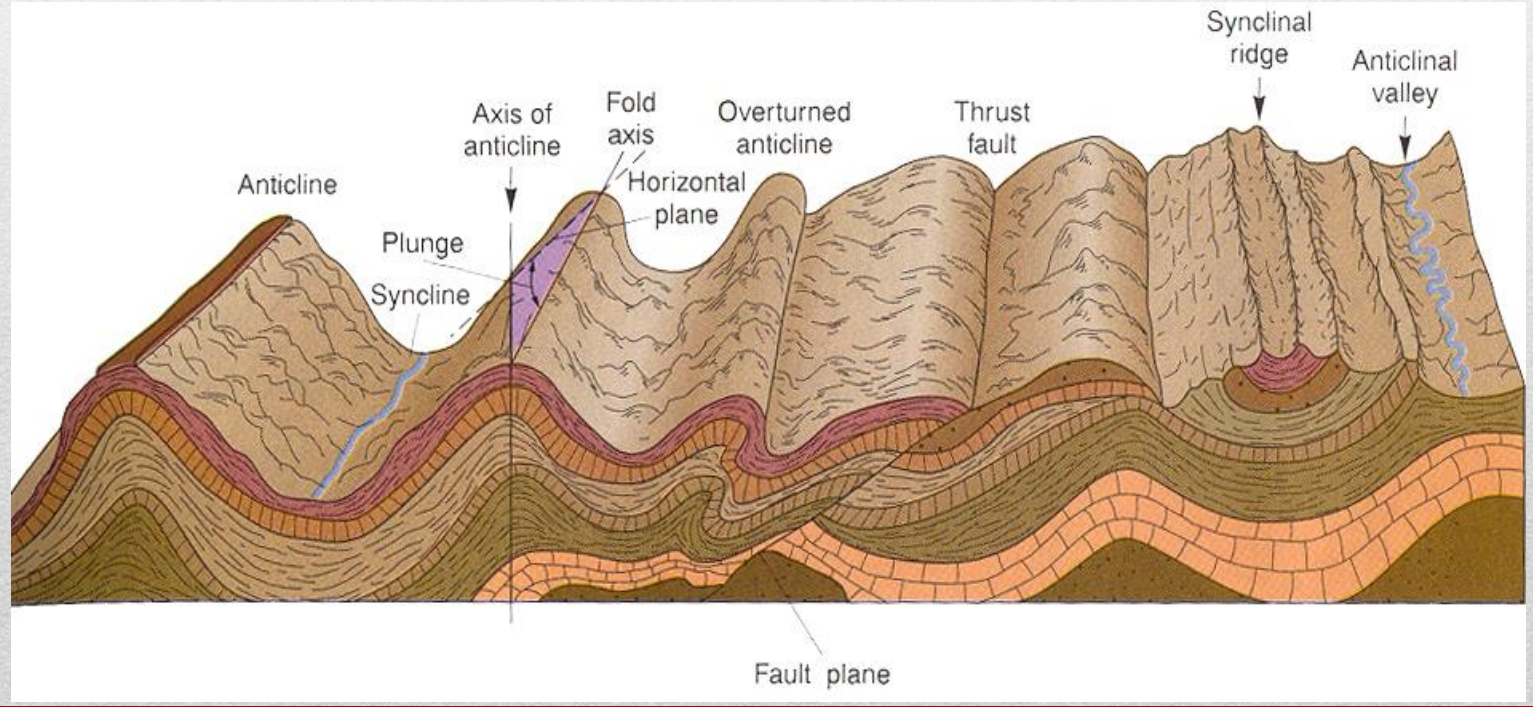
- **Supershear**
  - Occurs when the **propagation of rupture** is **faster** than the **velocity of shear-waves or surface waves** produced by the rupture
  - Supershear can produce **shock waves that produce strong ground motion** along the fault



- The **nature of the local earth materials and geologic structure strongly influences the amount of ground motion**
- Earth materials **behave differently in an earthquake**
- If the earth material causes the **P and S waves to slow down** the forward **energy is focused vertically**; this is known as **material amplification**
- This movement strongly **influences the ground motion** of an earthquake

Earthquake Shaking

- **Local geologic structures** can also influence the amount of shaking
  - **Synclines and fault-bounded sedimentary basins can focus seismic waves the way a magnifying lens focuses sunlight**
  - This causes **severe shaking in some areas and less intense shaking in others**



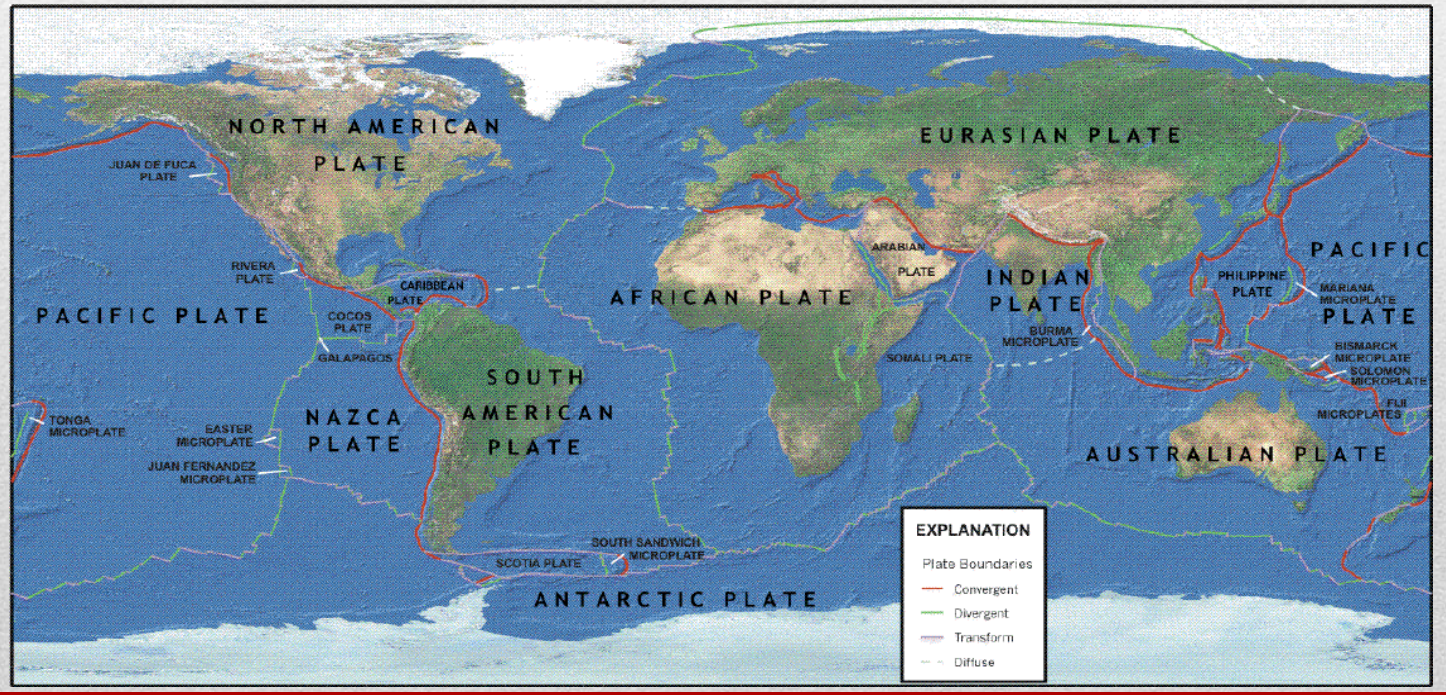
The Earthquake Cycle

- From the 1906 San Francisco earthquake observations were made that led to a hypothesis know as the **earthquake cycle**
- The **earthquake cycle proposes that there is a drop in elastic strain after an earthquake and a reaccumulation of strain before the next event**

1. **A long of inactivity along a segment of a geologic fault**
2. **Accumulated elastic strain produce small earthquakes**
3. **Consists of foreshocks happen hours or days before the main earthquake. In some cases this event may not happen**
4. **The main event is the *mainshock*, the major earthquake and its *aftershocks and the mainshock epicenter.***

Geographic Regions at Risk from Earthquakes

- ***Earthquakes are not randomly distributed***
- There are **well-defined zones along the boundaries of Earth's tectonic plates**



Geographic Regions at Risk from Earthquakes

- **Plate Boundary Earthquakes**
  - Earthquakes occur along all three types of plate boundaries
    - **Convergent**
    - **Divergent**
    - **Transform**
  - The world's greatest earthquakes which have happen in the last 100 years have been along **megathrust subduction zones**
    - These are called **megathrust earthquakes**

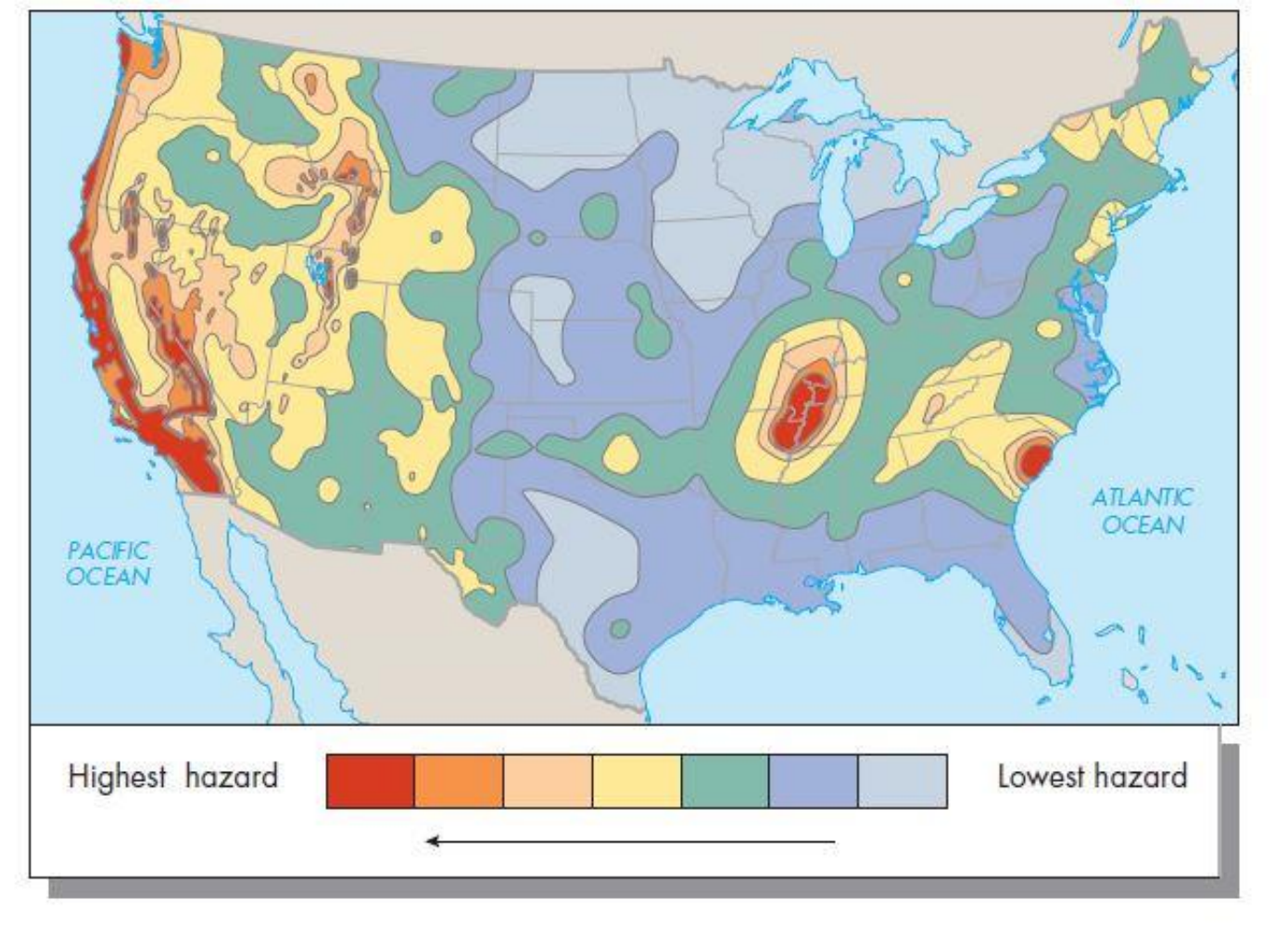
- Places like **Los Angeles, San Francisco**, and other places along **transform plate boundaries** often have earthquakes
- The states along the **Rocky Mountains (including Utah) experience many earthquakes**

- **Knowing the probably location, the magnitude and effects of an earthquake allows for plans to be made to decrease loss of life and damage**

Geographic Regions at Risk from Earthquakes

- **Intraplate Earthquakes**
  - **Less common**
  - **Can be large and extremely damaging**
  - They **don't happen often** so **people are less prepared for them**
    - There were **two large earthquakes 1811-12** during the winter in the central Mississippi Valley
    - These were felt all over the eastern states from New Orleans to Boston to Quebec City
    - Produced a intense surface deformation over a wide area of Memphis, Tennessee north to the confluence of the Mississippi and Ohio Rivers
    - These two earthquakes occurred along the New Madrid seismic zone, part of a geologic structure known as the Mississippi Embayment
    - It is figured that earthquakes happen along this embayment at a *recurrence interval*, once every several hundred years

Geographic Regions at Risk from Earthquakes

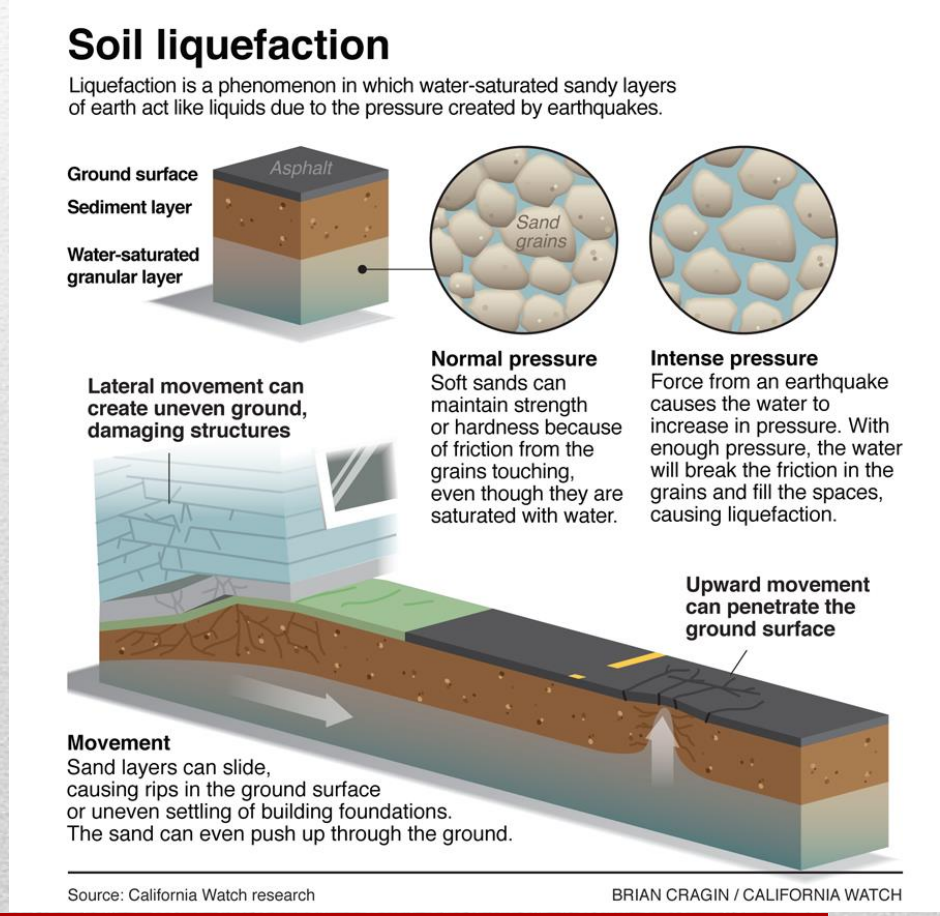


Effects of Earthquakes and Linkages with Other Natural Hazards

- **Shaking is not the only cause of death and damages during earthquakes**
  - **Earthquakes often cause linkages to other natural hazards**
- **Shaking and Ground Rupture**
  - A major ground rupture from an earthquake causing a short cliff is called a **Fault Scarp**
    - This cliff is not an "opening to the inside of the earth" like some movies insinuate
  - **Buildings can experience damage by violent shaking called ground acceleration**
    - This ground acceleration shaking causes the building to shake by matching its frequency or **resonance**
- **Liquefaction**
  - **Shaking of water-saturated material** Turns **clay soil to fluid resulting in subsidence, fracturing, and horizontal sliding** of the ground surface

Fault Scarp

Liquefaction



Effects of Earthquakes and Linkages with Other Natural Hazards

- **Regional Changes in Land Elevation**
  - **Vertical deformation of the land surface** is linked to large earthquakes
  - Includes regional uplift and subsidence of the earth's surface
  - Can cause substantial damage to coastal areas and along streams
- **Landslides**
  - **Landslides are the closest physical link to earthquakes**
  - Earthquakes are the most common trigger of landslides
  - Can be extremely damaging and cause a large loss of life
- **Fires**
  - **Happens when surface is displaced and electrical power and natural gas pipes break**
  - Larger threat when water mains break, roads and bridges broken, blocking fire equipment ability to get to fire and put it out
- **Disease**
  - **Outbreaks of diseases** sometime occur during large earthquakes because of the **loss of sanitation , housing, contamination of water** and other public health problems

Natural Service Functions of Earthquakes

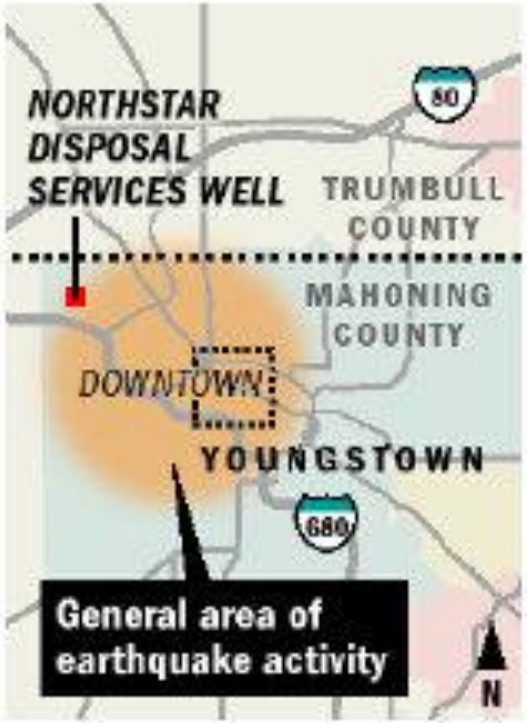
- Finding **benefits** from earthquakes can sound like it would be difficult, but there are some **natural service functions** from earthquakes
- **Groundwater and Energy Resources**
  - Movements of faults as a result of earthquakes allow the **underground flow of water, oil, and natural gas**
- **Mineral Resources**
  - Faulting from earthquakes may be responsible for the **accumulation or exposure of economically valuable minerals**, like **veins of gold, silver or other valuable minerals**
    - **Oquirrh Mountains (many types of minerals)**
- **Landform Development**
  - **Earthquakes** can form **scenic landforms** over long intervals of geologic time
    - **Some parts of central and southern Utah**
- Future Earthquake Hazard Reduction
  - By having **small earthquakes the tension is released** avoiding that "big one"

Human Interaction with Earthquakes

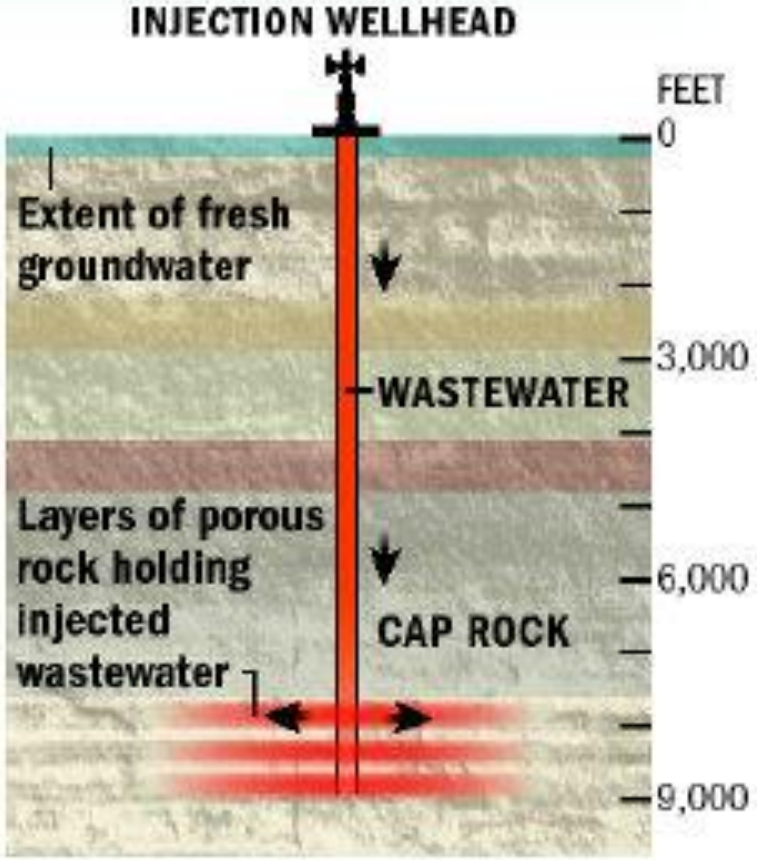
- **Earthquakes Caused by Human Activity**
  - **Four ways the actions of people** have caused earthquakes
    - **Over -Loading the Earth's crust with building a dam and reservoir**
    - **Injecting Liquid waste deep water into the ground through disposal wells**
    - **Creating underground nuclear explosions**
    - **Hydraulic Fracturing-exploring for oil and natural gas**

Earthquake zone

A wastewater disposal well triggered 12 earthquakes in the Youngstown area last year.



At a typical injection well, drilling wastewater is pumped from tanker trucks to storage tanks, then it is sent thousands of feet below ground into porous rock.



TOM BAKER | DISPATCH

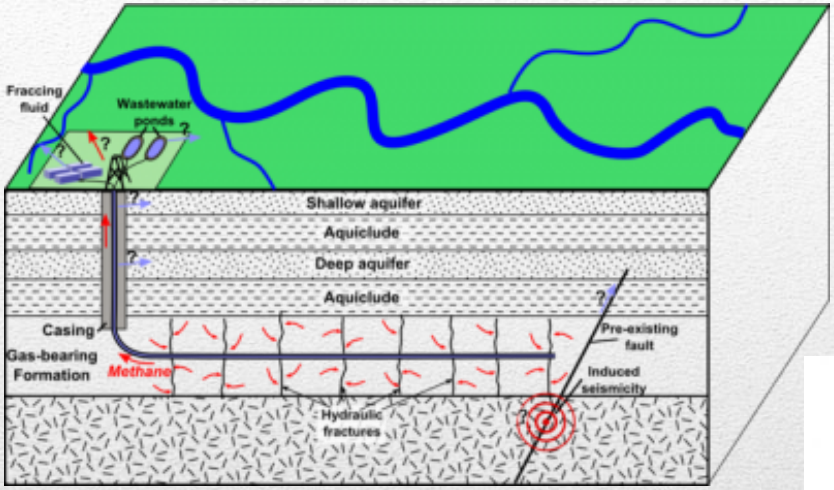
Human Interaction with Earthquakes

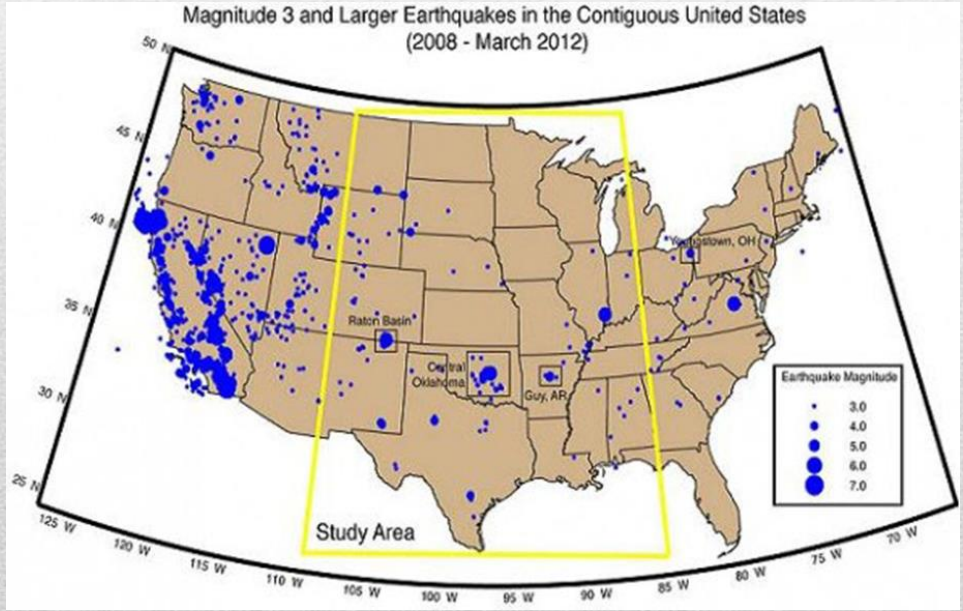
- **Loading the Earth's crust as in building a dam and reservoir**
  - **Water reservoirs may create or induce earthquakes**
    - The huge weight of the water can create or extend fractures in adjacent rock
    - Increases water pressure in the surrounding groundwater causing earthquakes
- **Injecting liquid waste deep into the ground through disposal wells**
  - **Deep Waste Disposal** was an experiment of the US Army in the 1960's
  - **This experiment** provided the direct evidence that injecting fluids into the earth can cause earthquakes
  - Increases underground fluid and pressure **which caused slippage of numerous fractures of metamorphic rock**
  - **When this was discontinued, the earthquakes quit, an important find**

Human Interaction with Earthquakes

- **Creating underground nuclear explosions**
  - During the **1960's (again) the testing of nuclear explosions was moved from the surface to underground protecting people living downwind**
  - It was thought that these **explosions could be used to release the seismic tension in underground rock**
  - It **really doesn't work**, and there is still the problem of having any nuclear explosions
- **Hydraulic Fracturing (Fracking)**
  - The **new way of looking for oil, coal, shale gas, or natural gas**
  - Found in Oklahoma, Pennsylvania, Ohio, and many other states
  - Started in 1947, lately being used more in the past 10 years
  - Besides the **environmental problems that can occur, earthquakes have been tied to fracturing**
  - In 2011, **Oklahoma experienced its largest earthquake**. It was thought to be linked to fracturing processes being practiced in the state, but the **USGS declared it was probably natural**
  - **Other earthquakes have been felt in areas where fracturing has been used**

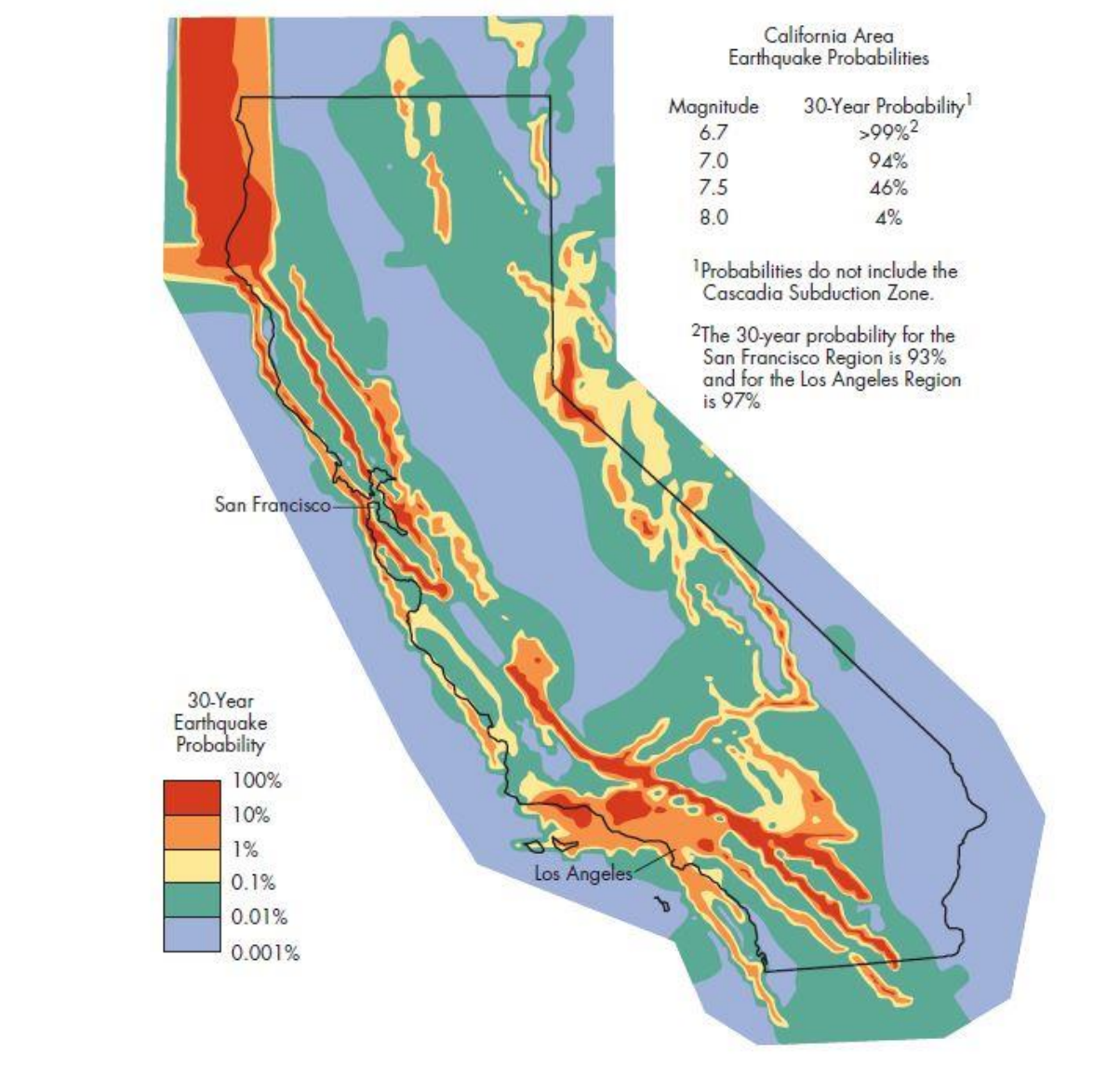
Fracturing and Earthquakes





Minimizing the Earthquake Hazard

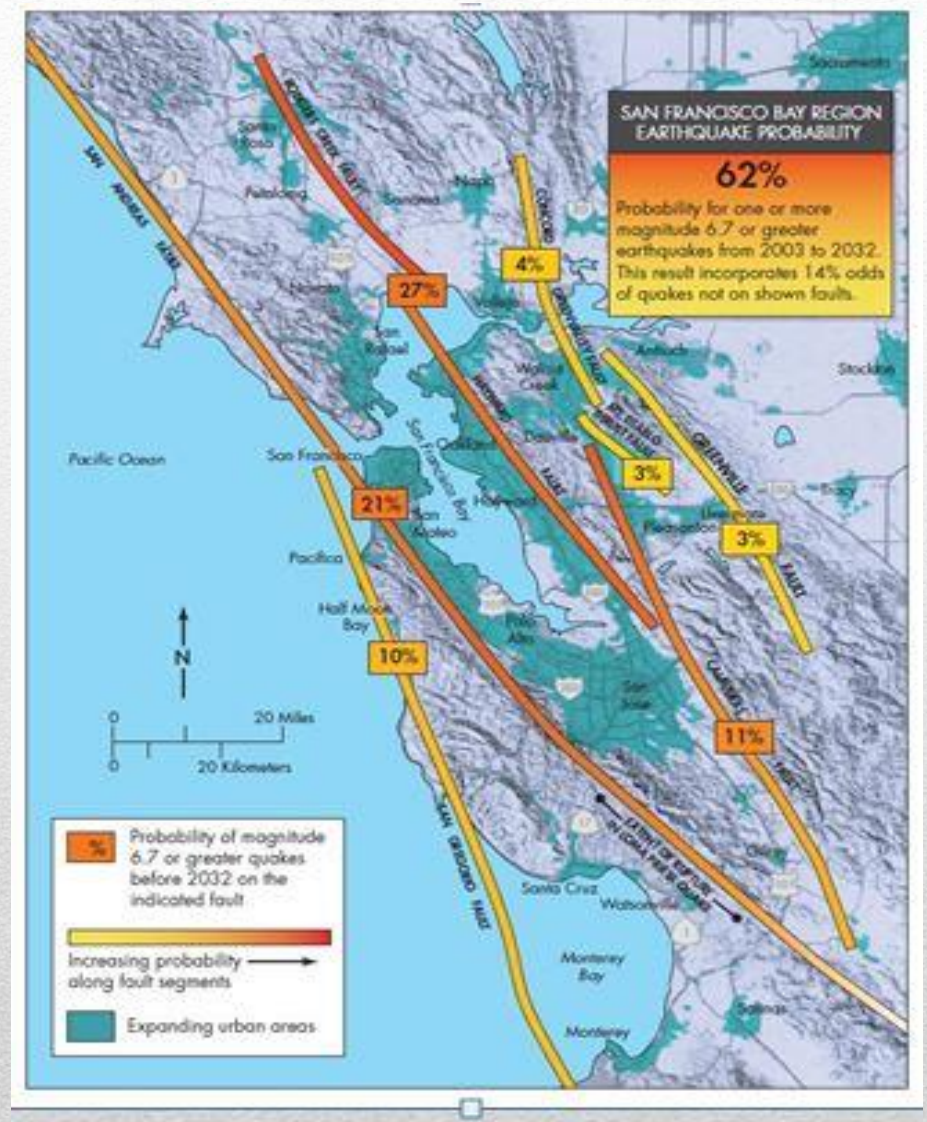
- **Earthquakes cause lots of damage and loss of life consequently there has been research into how to forecast an earthquake**
- It would be hoped that by forecasting earthquakes lives and damage can be decreased
- So the **National Earthquake Hazard Reduction Program was formed with these goals**
  - **Develop and understanding of the earthquake source**
    - Requires obtaining information about the physical properties and mechanical faults and develop models about the process
  - **Determine earthquake potential**
    - Study the seismically active regions to determine their paleoseismicity, identify active faults and rates of deformation
  - **Predict effects of earthquakes**
    - Obtain information needed to calculate the predict the ground rupture and shaking on buildings
  - **Apply research results**
    - The program educates individuals, communalities, states, and the nation about earthquakes



Identify Probability of Earthquake

Minimizing the Earthquake Hazard

- **Estimation of Seismic Risk**
  - Seismic hazard maps can be used to help formulate where earthquakes can happen
- **Short-term Prediction**
  - Active area of research
  - Relies on precursors, events or changes that occur prior to main shock
  - Doesn't always work, prediction a complex problem
  - If predictions actually are formulated they will be based on
    - Patterns and frequency of
    - Deformation of the ground surface
    - Seismic gaps along faults
    - Geophysical and geochemical changes



Shaking-Hazard Map

Minimizing the Earthquake Hazard

- **The Future of Earthquake Prediction**
  - Scientists have been **working on prediction but still haven't got a good system**
  - **Progress has been made on short-term, but long-term forecasting is still along way off**

- **Earthquake Warning Systems**
  - It is technically feasible that an earthquake warning system could be made that would give a 1 minute warning
  - But **if** there were false alarms, people would begin to not take them seriously

Perceptions and Adjustments to the Earthquake Hazards

- **Perception of the Earthquake Hazard**
  - Because **there aren't ways to predict or warn people of earthquakes there are problems with the perception of and adjustment to the earthquake**
  - Society **is vulnerable to catastrophic loss from large earthquakes due to old buildings, too big of buildings , and many other problems**

Perceptions and Adjustments to the Earthquake Hazards

- **Community Adjustments to the Earthquake Hazard**
  - Since we can't avoid living in earthquake prone areas, society needs to take steps to adjust to the earthquake hazard by doing these following steps to avoid these hazards
  - **Location of Critical Facilities**
    - Facilities which are critical to communities need to located in safe areas
  - **Structural Protection**
    - The need to build buildings so they don't fall down and kill people will make society safer if an earthquake should happen
  - **Education**
    - Education on what and how to protect yourself during an earthquake and how to build earthquake safe, decreases the hazards of earthquakes
  - **Increase Insurance and Relief Measures**
    - If you are in an earthquake prone area, take get earthquake insurance,
- **Personal Adjustments**
  - Make adjustments to your home to make it earthquake safe and have a plan if an earthquake happens